FEDERAL REPUBLIC OF GERMANY

Priority Document concerning the Submission
of a Patent Application

File number:	100 63 087.1
Application date:	18 December 2000
Applicant/patent holder:	Siemens Aktiengesellschaft, München/DE
Title:	Gradient coil system
IPC:	G 01 R 33/385

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Specification

GRADIENT COIL SYSTEM

The invention concerns a gradient coil system, in particular for a magnetic resonance device.

The magnetic resonance technology is a known technology for acquiring images of the inside of a body of an examination subject. In a magnetic resonance device, rapidly switched gradient fields are thereby superimposed onto a static basic magnetic field that is generated by a basic field magnetic system. Furthermore, the magnetic resonance device comprises a radio-frequency system which irradiates radio-frequency signals into the examination subject to excite magnetic resonance signals, and which acquires the generated magnetic resonance signals on the basis of which magnetic resonance images are produced.

The gradient system comprises a gradient coil system with gradient coils and controlled gradient intensifiers. One of the gradient coils generates for a specific spatial direction a gradient field that, in a desired ideal case, has exclusively a main field component that is collinear to the basic magnetic field, at least within an imaging volume. The main field component thereby exhibits a predeterminable main gradient that, at any arbitrary point in time, is, approximately the same size, independent of location, at least within the imaging volume. Since the gradient field is a temporally variable magnetic field, the aforementioned is true for any point in time, however an intensity of the main gradient is variable from one point in time to another point in time. The direction of the main gradient is normally set predetermined by the design of the gradient coil.

Due to the Maxwellian fundamental equations, contrary to the desired ideal case, gradient coils cannot be fashioned that exclusively exhibit the aforementioned main field component over the imaging volume. At least one accompanying field

component, which is directed perpendicular to the main field component, is thereby associated with the main field component.

Corresponding currents must be adjusted in the gradient coil in order to generate the gradient field. The amplitudes of the required currents are several 100 A. The current rise and fall rates (slew rate) are several 100 kA/s. For the current supply, the gradient coil is connected to a controlled gradient intensifier.

Via the switching of the gradient fields, stimulations can be excited in a living examination subject in magnetic resonance image acquisition. The gradient fields thereby acting upon the examination subject are characterized by a temporally varying magnetic flux density that generates eddy currents and induction currents in the examination subject. The intensity of the aforementioned electrical currents depends on, among other things, the cross-sectional area that the gradient field achieves, and on the temporal variation of the gradient field. Aforementioned currents thereby traverse regions of the examination subject with different electrical conductivity and thereby effect corresponding electrical voltages. If the voltage exceeds a specific threshold, this leads to excitation stimulations of the examination subject. For example, it is known from DE 42 25 592 A1 that, given switched gradient fields, the highest current values or, respectively, voltage values, are induced at the edge or, respectively, outside of the imaging volume, where the field deviation of the magnetic flux density of the gradient field is at a maximum, such that there the danger of stimulations is greatest.

To prevent such stimulations, it is known from DE 42 25 592 A1 to cover stimulation-sensitive regions outside of the imaging volume with a closed conductor loop. A result of this is a reduction of the currents induced in the covered region. Aforementioned coverings are, however, only possible outside of the imaging volume but not in edge regions of the imaging volume, because otherwise the linearity of the gradient fields (important for the image quality) in the imaging volume and the homogeneity of the basic magnetic field are impaired.

Furthermore, it is disadvantageous that the position of the conductor loops normally must also be adapted when a region of the examination subject to be imaged is modified.

DE 195 27 020 C1, in the framework of a hollow cylindrical gradient coil system for a transversal gradient coil, describes a combination of a segment gradient coil and a gradient coil that is composed of saddle shaped sub-coils. The advantages of both types of gradient coils should thereby be maintained, and their disadvantages are thereby reduced at the same time. A strong accompanying field component, which is stronger than the usable main field component, is cited as a disadvantage of the gradient coil that is composed of saddle shaped sub-coils. Among other things, the accompanying field component, and therefore the danger of stimulations as a result of rapidly switched gradients, should be clearly reduced via the combination.

It is an object of the invention to achieve an improved gradient coil system with which, among other things, high intensities of a rapidly switched gradient field can be achieved without stimulations of a living examination subject.

The object is achieved by the subject matter of claim 1. Advantageous embodiments are described in the subclaims.

According to claim 1, a gradient coil system comprises the following features:

- at least one gradient coil, with a conductor arrangement for generating a magnetic gradient field, that comprises a main field component that is collinear to a basic magnetic field and at least one accompanying field component that is perpendicular to the main field component, and
- at least one further conductor arrangement that is fashioned and arranged to generate an inhomogeneous magnetic field, such that the main field component is approximately unaltered at least in an area and the accompanying field component is reduced.

The undesired accompanying component can thereby be compensated at least in an area in which a living subject to be examined by means of magnetic resonance technology is extended. The gradient field pervading the examination subject can thereby be reduced to the magnetic resonance image-effective main field component, and thus a probability of stimulation of the examination subject can be reduced or, respectively, an intensity of the gradient field that can be used without danger can be increased.

Further advantages, features and details of the invention derive from the exemplary embodiments described in the following using the drawing. Thereby shown are:

Figure 1 a magnetic resonance device,

Figure 2 a layer of a hollow cylindrical gradient coil system of the magnetic resonance device,

Figure 3 sub-coils of a gradient coil fashioned saddle-shaped, and an appertaining shielding coil whose longitudinal conductor sections are arranged corresponding to a coaxial conductor,

Figure 4 sub-coils of a gradient coil, fashioned saddle-shaped, and an appertaining shielding coil whose longitudinal conductor sections are arranged narrowly adjacent, and

Figure 5 sub-coils of a gradient coil, fashioned saddle-shaped, and an appertaining shielding coil whose longitudinal conductor sections are arranged interlaced.

Figure 1 shows a magnetic resonance device in a perspective view. The magnetic resonance device thereby comprises a basic field magnetic system 110 to generate an optimally homogenous static basic magnetic field B_0 at least within an imaging

volume 120. Furthermore, the magnetic resonance device comprises a gradient coil system 200 for generating gradient fields. A movable bearing device 130 of the device serves, among other things, to position in the imaging volume 120 a to-be-imaged region of an examination subject borne on the bearing device 130. For reasons of clarity, further components of the device, for example an antenna system, are not shown.

The gradient coil system 200 is fashioned substantially hollow-cylindrical and comprises, among other things, a longitudinal gradient coil for generating a magnetic gradient field with a main gradient in the direction of the basic magnetic field B_0, two transversal gradient coils for generating magnetic gradient fields with main gradients perpendicular to the basic magnetic field B_0, cooling devices, shim devices and shielding coils associated with the respective gradient coils.

Figure 2 shows a hollow-cylindrical layer 205 of the gradient coil system 200, within which one of the transversal gradient coils is arranged. The transversal gradient coil comprises four sub-coils 211 to 214 fashioned saddle-shaped, for example as what are referred to as fingerprint coils in an embodiment. A course of a conductor of one of the sub-coils 211, 212, 213 or, respectively, 214 is only schematically outlined for the four sub-coils 211 to 214 and is exemplarily shown with few windings. The hollow-cylindrical gradient coil system 200 comprises a hollow-cylinder principal axis 201 that is parallel to a directional vector of the basic magnetic field B_0.

As an exemplary embodiment of the invention, Figure 3 shows sub-coils of a gradient coil that are fashioned saddle-shaped, and of an appertaining shielding coil whose longitudinal conductor sections are arranged corresponding to a coaxial conductor. For explanatory purposes, the saddle-shaped sub-coil 201 of the transversal gradient coil from Figure 2 is resorted to as an example. In Figure 3, the sub-coil is idealized and is exemplarily shown with only one winding. The winding comprises two arc-like conductor sections 221 and 222 extending in

circumferential direction of the hollow cylinder, as well as two straight longitudinal conductor sections 231 and 232 extending parallel to the hollow cylinder principal axis 201. To feed a corresponding electrical current into the turn, the arc-like conductor section 221 comprises an interruption forming two connecting points via which the sub-coil 211 is correspondingly fed current. Electrical current flowing in the arc-like conductor sections 221 and 222 thereby essentially effects a desired main field component of the magnetic gradient field that can be generated by the gradient coil. On the other hand, the current flowing in the longitudinal conductor sections 231 and 232 essentially effects at least one undesired accompanying field component of the gradient field.

Arc-like conductor sections 321 and 322 of a likewise saddle-shaped sub-coil of a shielding coil associated with the gradient coil are arranged in a hollow cylindrical layer, which, with respect to the layer 205 of the sub-coil 221, is localized further outside in the gradient coil system 200. Similar to the arc-like conductor section 221 of the gradient coil, the arc-like conductor section 321 of the shielding coil is also interrupted for feeding current. The shielding coil is switched with the gradient coil such that current flowing in the sub-coil 221 simultaneously flows with an opposite direction in the sub-coil of the shielding coil. In addition to the arc-like conductor sections 321 and 322, the sub-coil of the shielding coil, which is shown idealized with only one winding, also has radially-fashioned conductor sections 341 to 344 and tubular longitudinal conductor sections 331 and 332. The tubular conductor section 331 or, respectively, 323 [sic] of the shielding coil and the longitudinal conductor section 231 or, respectively 232 of the gradient coil, electrically insulated from one another, are arranged forming a coaxial conductor. The tubular conductor sections 331 and 332 of the shielding coil, with respect to the corresponding longitudinal conductor sections 231 and 232 of the gradient coil, are simultaneously traversed by currents of equal strength but opposite direction given operation of the gradient coil system 200. As a result of the coaxial conductor arrangement, an inhomogeneous magnetic field effecting the current flow in the tubular conductor sections 331 and 332 compensates the undesired

accompanying field component which is essentially caused by the current flow in the longitudinal conductor sections 231 and 232 of the gradient coil. Therefore, the desired main field component of the magnetic gradient field remains unaltered.

As a further exemplary embodiment of the invention, Figure 4 shows saddle shaped sub-coils of a gradient coil and of an associated shielding coil whose longitudinal conductor sections are arranged tightly adjacent. The conductor arrangement of Figure 4 essentially differs from the arrangement of Figure 3 by a different configuration and fashioning of the longitudinal conductor sections of both the gradient coil and the corresponding shielding coil. However, operating method and function concerning the compensation of the accompanying field component are corresponding. In addition to the arc-like conductor sections 221 and 222, the saddle-shaped sub-coil of the gradient coil comprises radially fashioned conductor sections 241 to 244 and longitudinal conductor sections 233 and 234. The longitudinal conductor sections 233 and 234 are thereby situated in a hollow-cylindrical layer of the gradient coil system 200 which, with respect to a hollow-cylindrical layer of the arc-like conductor sections 221 and 222, is arranged at a distance and further outwards within the gradient coil system 200. In addition to the arc-like conductor sections 321 and 322, the sub-coil of the shielding coil comprises radially fashioned conductor sections 351 to 354 and longitudinal conductor sections 333 and 334. The longitudinal conductor sections 333 and 334 of the shielding coil, electrically insulated from the longitudinal conductor sections 233 and 234, are arranged in a hollow-cylindrical layer that encloses the layer of the longitudinal conductor sections 233 and 234 of the gradient coil in an immediately adjacent fashion. The arc-like conductor sections 321 and 322 of the shielding coil, with respect to the layer of the longitudinal conductor sections 333 and 334, are situated in a hollow-cylindrical layer which is arranged further outside in the gradient coil system 200.

As a further exemplary embodiment of the invention, Figure 5 shows saddle-shaped sub-coils of a gradient coil and of an associated shielding coil whose

longitudinal conductor sections are arranged interlaced. In contrast to the conductor arrangement of Figure 4, in Figure 5 longitudinal conductor sections 235 and 236, radially fashioned conductor sections 261 to 264 of the gradient coil, longitudinal conductor sections 335 and 336, and radially fashioned conductor sections 361 to 364 of the shielding coil are arranged and fashioned such that the longitudinal conductor section 235 or, respectively, 236 of the gradient coil exhibits an interlacing with respect to the longitudinal conductor section 335 or, respectively, 336. Given said interlacing, the longitudinal conductor sections 235 and 236 of the gradient coil are arranged in a hollow-cylindrical layer of the gradient coil system 200 which is situated further outside in the gradient coil system 200 than a hollow-cylindrical layer in which the longitudinal conductor sections 335 and 336 of the shielding coil are arranged. Therefore, a good compensation of the accompanying field component, in particular for an area in the inside of the hollow cylinder in which an examination subject can extend, is achieved due to a number of turns of the gradient coil that is normally greater vis-à-vis the shielding coil.

Patent claims

1. Gradient coil system (200), in particular for a magnetic resonance device comprising the following features:

- At least one gradient coil with a conductor arrangement for generating a magnetic gradient field that comprises a main field component collinear to a basic magnetic field (B_0) and at least one accompanying field component that is perpendicular relative to the main field component, and
- at least one further conductor arrangement that is fashioned and arranged for generating an inhomogeneous magnetic field, such that, at least in one area, the main field component is approximately unaltered and the accompanying field component is reduced.

2. Gradient coil system (200) according to claim 1, comprising the following features:

- The conductor arrangement of the gradient coil comprises at least one conductor section (231 to 236) whose longitudinal course has a component parallel to the basic magnetic field (B_0), and
- the further conductor arrangement comprises at least one conductor section (331 to 336), which is allocated to the conductor section (231 to 236) of the gradient coil, whose longitudinal course is oriented approximately parallel relative to the basic magnetic field (B_0) and which can be operated with an opposite current direction with respect to a current direction in the conductor section (231 to 236) of the gradient coil.

3. Gradient coil system (200) according to claim 2, whereby the conductor section (331 to 336) of the further conductor arrangement is arranged approximately parallel relative to the conductor section (231 to 236) of the gradient coil.

4. Gradient coil system (200) according to one of the claims 2 or 3, whereby the conductor sections (231 to 236, 331 to 336) are arranged tightly adjacent.

5. Gradient coil system (200) according to any of the claims 2 to 4, whereby one of the conductor sections (231 to 236, 331 to 336) is fashioned and arranged such that it coaxially encloses the other.

6. Gradient coil system (200) according to any of the claims 1 to 5, whereby the conductor arrangements are fashioned and arranged for guiding an approximately same current intensity.

7. Gradient coil system (200) according to any of the claims 1 to 6, whereby the gradient coil comprises at least one saddle-shaped sub-coil (211 to 214).

8. Gradient coil system (200) according to any of the claims 1 to 7, whereby the further conductor arrangement comprises at least one conductor section (321 to 364) of a conductor arrangement of a shielding coil appertaining to the gradient coil.

9. Gradient coil system (200) according to claim 8, whereby the shielding coil comprises at least one saddle-shaped sub-coil.

10. Gradient coil system (200) according to any of the claims 1 to 9, whereby the gradient coil system (200) is fashioned such that it approximately corresponds to a hollow cylinder, and the hollow cylinder exhibits a hollow cylinder principal axis (201) oriented parallel to the basic magnetic field (B_0).

11. Gradient coil system (200) according to claim 10, whereby the conductor arrangement of the gradient coil comprises conductor sections (221 to 236) which are at a different radial distance with respect to the hollow cylinder principal axis (201).

12. Gradient coil system (200) according to one of the claims 10 or 11, whereby the further conductor arrangement comprises conductor sections (321 to 336) which are differently radially distanced with respect to the hollow cylinder principal axis (201).

13. Gradient coil system (200) according to one of the claims 10 to 12, comprising the following features:

- The conductor arrangement of the gradient coil comprises at least one conductor section (235, 236) whose longitudinal course comprises a component parallel to the hollow cylinder principal axis (201),
- the further conductor arrangement comprises at least one conductor section (335, 336) which is arranged approximately parallel to the conductor section (235, 236) of the gradient coil, and
- the conductor section (235, 236) of the gradient coil exhibits a greater distance with respect to the hollow cylinder principal axis (201) than the conductor section (335, 336) of the further conductor arrangement.

Abstract

Gradient coil system

A gradient coil system (200), in particular for a magnetic resonance device, comprising the following features:

- At least one gradient coil with an conductor arrangement for generating a magnetic gradient field comprising a main field component collinear to a basic magnetic field (B_0) and at least one accompanying field component that is perpendicular to the main field component, and
- at least one further conductor arrangement that is fashioned and arranged for generating an inhomogeneous magnetic field, such that, in at least one area, the main field component is approximately unchanged and the accompanying field component is reduced.

Figure 3